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DISTRIBUTION OF SOLID MATTER IN THICK AND THIN EGG WHITE[1]

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Stored eggs kept under optimum conditions of temperature and humidity and free from molds and putrefactive bacteria may, nevertheless, exhibit tendencies toward undesirable changes which cause the eggs to lose much of their original appearance and attractiveness.

One of the most prominent of these changes is the slow liquefaction of the firm, jelly-like white. As a result of this liquefaction the egg white appears watery. This condition is found very objectionable in the market egg and frequently results in a lowering of grade and price of the egg with a corresponding loss to the owner.

Up to the present time investigations of egg white have not differentiated between the thick and the thin varieties in kind studied or in results obtained. Accordingly, there has existed no experimental evidence which would serve as a basis for an explanation of the progressive liquefaction often encountered in stored eggs.

The results of investigation of thick and thin white can hardly be considered comparable until the amount of dry matter present in each of these substances is known and any variation in this dry matter is taken into account. To establish a basis of comparison of thick and thin white, as a first step in studies on watery whites, the distribution of dry matter in thick and thin white, and its possible variability in different eggs were investigated.

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METHODS

The method of determining total solids was that recommended by Hertwig (1925): A sample of 2 grams of liquid white was weighed into a covered aluminum dish which had previously been dried at 127–133° C, allowed to cool in a desiccator, and weighed soon after attaining room temperature. The dish was uncovered and, with contents and cover, dried in the oven at 127–133° C for one hour. The dish was then covered, transferred to desiccator to cool to room temperature, and weighed. The method has proved satisfactory and capable of very close checks.

Refractive index was measured with the Spencer Refractometer, Abbe type. The investigation included normal eggs up to 40 days of age from more than 30 birds. The eggs were stored under room conditions.

RESULTS

Without exception, the refractive index and total solids of thin white were found identical within experimental limits with those of thick white from the same egg in eggs more than 1 day old. Occasional small and random differences appeared in eggs less than 1 day old.

TABLE 1

Hen	Age of egg, days	White	Solids	Refractive index 20°C
D 512	1	thin	11.24	1 3551
		thick	11.26	1.3550
	2	thin	11 76	1.3559
		thick	11.72	1 3559
	3	thin	11.80	1.3561
		thick	11.84	1.3562
D 511	2	thin	12.25	1.3569
		thick	12.22	1.3568
	20	thin	13.08	1.3582
		thick	13.12	1.3582
	30	thin	14.71	1.3610
		thick	14.74	1.3610
	39	thin	15.26	1.3620
		thick	15.22	1.3620

Representative data are included in detail in table 1; all data secured are presented graphically in figure 1. The values for percentage solids in thick and thin white from the same egg have been plotted against the corresponding average refractive index, since these measurements seem to be the same for each kind of white. The relation is

practically linear regardless of the variation in age or composition of the white.

In the fresh eggs studied the egg-white solids were found to vary chiefly in the range 10.7 to 12.9 per cent, with a corresponding refractive index variation of 1.3540 to 1.3580. A few extremes were found outside of these limits, values as high as 13.5 per cent and as low as 9.6 per cent being observed.

Eggs from the same hen showed much less variation and in many cases a high degree of uniformity. The percentage of solids in the white of stored eggs tended to increase in proportion to an increase in refractive index; these changes were in general more pronounced in the eggs which showed greater shrinkage.

DISCUSSION

The refractive index shows a steady increase with age but maintains throughout the same relation to total solids, as demonstrated in figure 1. The increase in concentration of solids is undoubtedly due to the disappearance of water from the white. This loss may take place in two ways, namely, by escape of water vapor through the

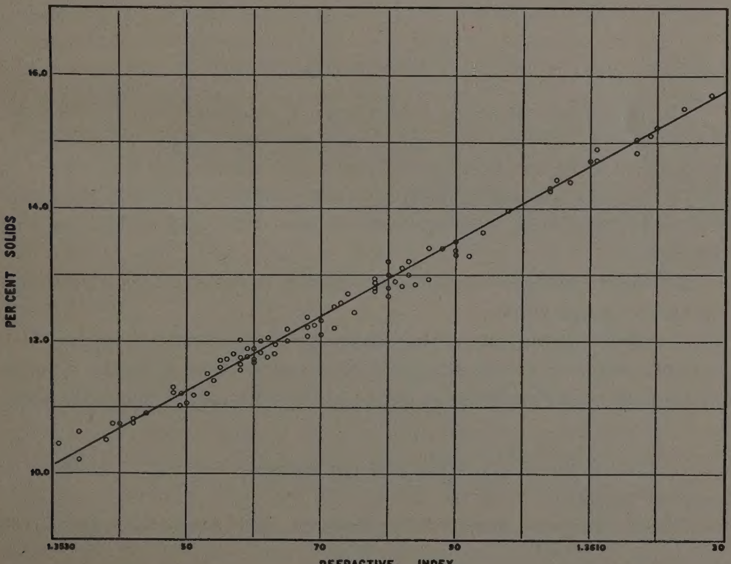

Fig. 1. The relation of the refractive index of egg white to its solids concentration.

shell and by diffusion of liquid water into the yolk. In order that equality of refractive index and total solids may persist, there must exist, between thick and thin white, a rapid equilibrium with respect to water. The loss of carbon dioxide and the gradual disappearance of thick white seem to have no bearing on this relation.

It is believed that the lack of complete agreement between refractive index and total solids shown in figure 1 is due chiefly to errors in determinations of solids, since any one set of determinations of solids, when plotted against refractive index, gave lines parallel to those of other sets. This suggests small variations in the drying treatment. A variation in the mineral constituents of the egg white solids may also account for part of the disagreement.

Romanoff (1929) has reported distinct differences in dry matter between the thick and thin white from the same egg. His results, which are based on the examination of only 5 eggs, most certainly do not agree with the results of our examinations. These, including a far greater number of eggs, show no exception, outside the limits of error, to the statements made above. The additional fact of equality in refractive index is conclusive support for the findings from determination of solids.

SUMMARY

The percentage of solids is the same in thick and thin white from the same egg, whether the egg is old or fresh. This conclusion is supported by the fact that the refractive indices are also the same.

The solids variation in fresh eggs was found generally in the range 10.7 to 12.9 per cent with extremes as low as 9.6 and as high as 13.5 per cent.

Refractive index measurements serve as a rapid means of estimating solids in egg white.

A rapid equilibrium with respect to water exists between thick and thin white in the same egg. The concentration of water remains the same in each regardless of losses to the yolk and through the shell.

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MEASUREMENT OF DETERIORATION IN THE STORED HEN'S EGG[1]

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INTRODUCTION

If the meaning of the term 'freshness,' as applied to an egg, be restricted to indicate the degree to which the egg has retained its original internal and external quality during storage, then it follows that age, as a criterion of egg freshness, is excluded from consideration. This, within limits, is entirely justifiable, since variations exist not only in respect to the intrinsic keeping powers and initial quality of the individual egg, but also in the storage conditions to which the eggs may have been subjected. By the proper selection of eggs and a suitable control of their storage conditions, time as a factor governing the freshness of eggs may, for practical purposes, be to a certain extent eliminated. The other extreme can also be attained: eggs may be caused to deteriorate at a rapid rate. Unfortunately it is not usually feasible or profitable to modify commercial storage methods so as to achieve the optimum conditions. As a consequence certain undesirable processes may occur.

Several of the changes in the stored hen's egg are sufficiently marked to be noticeable to anyone concerned with the keeping of eggs at or near their original fresh condition. These changes are shrinkage, liquefaction of the thick white, and passage of water into the yolk.

Loss of water from the egg can occur without noticeable change in other respects. Furthermore, loss of water can be prevented, yet thick white liquefaction may proceed at a rapid rate. The loss of water or of carbon dioxide from the egg may be caused to take place, each in the absence of the other, by properly controlling conditions; hence it is possible to test the above statements experimentally. This

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was done by storing 30 eggs in a desiccator over calcium chloride in an atmosphere maintained at 5 per cent carbon dioxide. In this lot of eggs water was removed at a rapid rate by the calcium chloride, while the carbon dioxide concentration was kept constant. A similar lot of eggs was stored in a desiccator over 5 per cent sodium hydroxide solution. Under these latter conditions a high humidity was maintained while carbon dioxide was rapidly removed from the storage atmosphere and, in turn, from the eggs. After 26 days all eggs of the first lot had air spaces ¼ to ½ inch in depth, showing extensive shrinkage, yet the interior quality was excellent. Thick white constituted on the average 52 per cent of the total white. In the second lot very little shrinkage was apparent on candling; nevertheless the eggs were as a whole badly liquefied. The whites averaged only 30 per cent as thick white.

It was found experimentally that the eggs on which figure 4 is based showed rates of shrinkage not at all comparable to the keeping qualities as found in the yolk and in the thick white. A comparison of these lots of eggs is given in table 1. This is further evidence in favor of the view that loss of water is a relatively minor type of deterioration and is not, in itself, responsible for other changes which may take place in stored eggs.

TABLE 1

COMPARISON OF KEEPING QUALITIES WITH RATES OF SHRINKAGE OF EGGS STORED AT 86° FAHRENHEIT.*

Hen	General keeping qualities	Average per cent weight lost per egg per day
A	Excellent	0.678
B	Fair	0.627
C	Poor	0.542

* These are the same eggs as those shown in figure 4.

Holst and Almquist (1931) showed that the loss of water from egg white is uniformly distributed throughout thick and thin white, since the concentration of solid matter in one remains equal to that in the other with varying age of the egg, although increasing regularly with the disappearance of water. These changes in the whites are thus proportionate. *Hence, if shrinkage is the only change, the percentage of total white in the form of thick white will remain constant for any one egg.*

For the above reasons, shrinkage, the only one of the various storage changes which may be reliably detected by candling, is of little value as an index to egg quality, inasmuch as it often fails to parallel other departures of the egg from a fresh condition and becomes significant only in extreme stages.

It is well known that 'watery whites' are associated with weakened and easily broken yolk membranes, yet the extent to which these changes may be correlated with each other has, up to this time, not been demonstrated. The mechanism of thick white liquefaction is at the present time not well understood. However, certain relations between this liquefaction and yolk depreciation have been studied in order to establish a basis of comparison for methods which measure these types of deterioration.

The actual passage of water from the white into yolk may be shown by analysis. The average moisture content of the yolks of fresh eggs examined during some of this work was 48.02 per cent, as compared with a value of 54.33 per cent secured from the yolks of eggs stored for 10 days at 86°F. At the same time the average yolk weights increased from 15.62 to 17.58 grams.

The various changes in egg yolks are all attributable to osmotic forces operating so as to cause a passage of water from the white to the yolk. The water content of fresh yolk is in the neighborhood of 48 per cent, while that of fresh white normally is between 85 and 90 per cent. This difference in concentration of water creates a tendency for water to pass into and dilute the contents of the yolk membrane. One of the first to note this effect was Greenlee (1911). In the fresh egg, where the difference in water content is at the maximum, the osmotic forces are greatest but may largely be controlled by at least one other factor.

The water which thus diffuses into the yolk produces two effects, both of which are undesirable. To make room for the incoming water, the yolk membrane is compelled to stretch and is thereby weakened. Only in very rare cases, however, will this effect result in the breaking of the yolk while inside the shell. A second and perhaps more serious effect is the marked increase in fluidity of the yolk substance.

The fresh yolk, when the egg is broken onto a flat surface, will stand up well, but a yolk which has absorbed much water will slump down rapidly because of its increased fluidity. This slumping down causes the yolk to assume a flat shape much different from that of a sphere which, of all bodies, requires the least surface for a given

volume. A greater membrane area is thus suddenly required; this, in conjunction with the previously mentioned weakening of the membrane, often sets up a stress which the membrane cannot resist and the yolk breaks.

A further effect aiding those mentioned is due to the disappearance of all but small amounts of thick white as such in these serious stages of deterioration. The mechanical support offered to the yolk by firm thick white is lost as the thick white disappears.

METHODS OF MEASURING DETERIORATION

There remain then two trends which may be followed with assurance, i. e., the changes in the yolk and the changes in the thick white.

A method of measuring the first of these has been described by Sharp and Powell (1930). A factor which they call the yolk index, representing the quotient of the yolk height and yolk width as measured when the yolk is placed on a flat surface, apparently decreases with the progressive deterioration of the egg. It also decreases more rapidly with increasingly unfavorable storage conditions such as high temperature, etc. The lowering of the yolk index is probably directly associated with the passage of water into the yolk.

This procedure is confined to the yolk and furnishes no clew as to the initial condition of the egg in respect to the amount of thick white. To quote Sharp and Powell, ''Some fresh eggs, however, may have a low interior quality, especially a watery condition of the white, so the standards of comparison must be modified to exclude such eggs.''

This watery condition of the white in fresh eggs is of as much interest to the investigator as is the gradual liquefaction of eggs during storage. Our researches, though as yet of a preliminary nature as far as these properties, which are difficult to trace are concerned, lead to the suggestion that in the fresh egg the percentage of the total white which is in the form of thick white is directly related to the keeping qualities of an egg. Where other factors may be considered equal, the higher percentage of thick white indicates superior keeping qualities.

A group of 150 fresh eggs gave 62 as the average percentage of the total white existing in the form of thick white, while the individual values ranged from 45 to 90 per cent. Thus even fresh eggs vary greatly in this respect and, on the average, may have whites already 40 per cent liquefied.

If the same yolk is allowed to stand on a flat surface, the yolk index decreases continuously with time so that measurements must be made

after an arbitrary time interval. Sharp and Powell secured good agreement by working in this fashion. This feature, however, detracts seriously from the applicability of such a test to experimental work.

Furthermore, the yolk must be carefully separated from the white and dried with a towel while held in the hand. The assumption that this excessive handling has no effect on the yolk is questionable. Our experience has shown that yolks far removed from a condition of freshness can be so handled only with great risk of breaking them. It is much easier to remove the yolk cleanly from the surrounding white and measure the white itself.

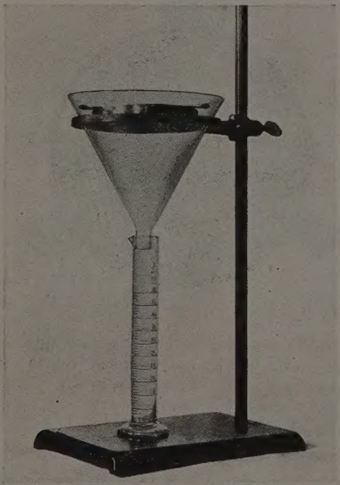

Fig. 1. Assembled apparatus used for the separation of thick and thin white and their volumetric measurement.

A second method of following storage depreciation, one which also furnishes an idea of fresh quality, consists of measuring the amount of white present in the firm jelly-like condition known as thick white. This procedure has been used in this laboratory for some time.

The apparatus required is shown in figure 1. It consists of three simple parts: a funnel, a graduated cylinder, and a specially constructed sieve. The only important specifications are those of the sieve (fig. 2), which has a diameter of 4 inches, a ½-inch raised rim, and a mesh of 9 per inch. The three tabs on the rim are for supporting the sieve inside of the funnel.

For the purpose of making measurements of thick white the egg is first broken into a standard-sized Petri dish. The yolk is removed, care being taken to separate the yolk and leave in the dish any adhering white. The white is then poured into the sieve mounted in the funnel which in turn delivers into the graduated cylinder. Thick white in good condition does not penetrate the sieve. In practice the sieve was gently rocked by hand in order to insure that thin white, which has the same density as thick white, was not held away from the openings by thick white. In a few seconds all thin white runs through.

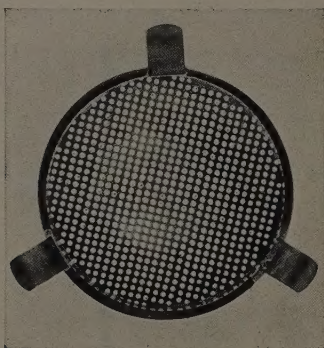

Fig. 2. Sieve used in the separation of thick and thin white in the apparatus shown in figure 1. The sieve itself is one used by Dr. S. L. Parker in her studies on individual and seasonal variations in the thick egg white (unpublished data).

When the penetration by thin white has slowed to a drop every few seconds the volume in the graduated cylinder is read to ½ cc. The sieve is then tilted and the thick white also allowed to run into the cylinder. The difference between first and final volumes represents the volume of thick white. This, expressed as percentage of total volume, gives the figures used at this laboratory to express the interior quality of eggs. Since, as previously mentioned, the densities and the concentration of solid matter are the same in both types of white from any one egg, the volume percentage of thick white is the same as the weight percentage. It is, furthermore, independent of shrinkage.

One source of error is the white unavoidably left behind in the petri dishes because of incomplete drainage. This error is small and assumes constancy for all eggs when dishes of the same size are used. A second source of error is due to the white required to wet the sieve and the portions of the funnel and cylinder with which the

white comes in contact, but this error may be balanced out by running the egg whites through as rapidly as proper measurements can be taken, keeping the apparatus wet. Thus the error due to this effect will apply only to the first and possibly the second measurements.

A fair degree of reproducibility may be obtained by this method in evaluating the condition of eggs which may be expected to be closely similar and in getting the same results by repeated trials with the same egg. In table 2 are summarized the results from measurements on series of eggs from the same birds. These eggs were all about one day in age.

TABLE 2

THE DISTRIBUTION OF THICK WHITE IN FRESH EGGS

Hen No.	Volume in cubic centimeters		Per cent thick white	Hen No.	Volume in cubic centimeters		Per cent thick white
	Thick white	Total white			Thick white	Total white	
C-52	21.0	36.0	58	C-21	15.5	25.5	61
	18.0	31.0	58		15.0	27.0	56
	19.0	33.0	58		15.5	25.5	61
					15.5	26.0	60
D-965	22.5	36.5	62	A-60	19.5	31.5	62
	27.0	42.0	64		18.0	29.5	61
	23.0	36.0	64		17.0	27.0	63
	20.5	33.0	62		17.5	28.0	62
1370	18.0	22.0	82	B-77	16.0	27.0	59
	14.0	18.0	78		14.0	24.0	58
	15.0	20.0	75		16.0	26.5	61
	17.5	21.5	81				
B-125	24.0	37.0	65	D-842	12.0	25.5	47
	21.0	33.5	63		12.0	25.0	48
	22.5	35.0	64		13.0	27.0	48
	24.0	39.5	62		11.5	23.5	49

It is worthy of note that the percentage column of table 2 shows in each series the least variation as compared to the other two, showing that the thick white percentage tends to be independent of variations in total amount of white and in egg size. Obviously both the eggs and the method must be very uniform to achieve these results.

EXPERIMENTAL METHOD

Since it is well known that thick white disappearance and passage of water into the yolk are found to occur together, it became of interest to secure some conception, first, of the rate of these processes, and second, as to whether they are simultaneous or not.

To investigate these questions the method last described above was used to detect changes in the thick white. Following the simplest manner of detecting the passage of water to the yolk, the yolks were carefully removed from the egg, freed from adhering white, dried briefly by rolling on soft absorbent paper, and weighed. Yolks from eggs which had been stored for some time often broke, even with the most careful treatment, making it necessary to discard all data from the eggs which supplied these yolks.

The storage was carried out at two temperatures, 64° F and 86° F. The humidity was kept constant and the carbon dioxide was removed by a 15 per cent solution of sodium hydroxide kept in the storage space. These temperatures are, of course, much higher than commercial storage temperatures, but have the advantage of shortening the experimental period by accelerating processes which occur at much slower rates under conditions more favorable to the keeping of the egg.

At the lower temperature data were taken at approximate 5-day intervals over a total period of 25 days, while at the higher temperature data were taken at 2-day intervals over a 10-day period.

On the assumption that a single bird generally would produce an egg of uniform characteristics, the work was broken up into a series of studies of the eggs from individual birds. This was expected to reduce as far as possible, the influence of variables such as egg size, shell texture and porosity, initial percentage of thick white, yolk weight, and other probable, but as yet unknown, sources of deviation. Results which are much clearer cut may be obtained by working in this way; those which have been obtained are a justification of the assumption. They were distributed among the various storage periods in a uniform manner, so that any one set of measurements usually would give data on eggs from all the different times of storage.

None of the eggs were protected in any way such as by oil dipping.

The data secured have been condensed and presented in graphic form in figures 3 and 4. Each point on these curves represents the average condition of at least four eggs at the designated time. For all but a few of these points the number of eggs is five or more.

Not all of the data have been shown, since to do so would result only in a repetition of certain type cases. Enough has been included to represent the extreme and mean cases and the trends common to all.

DISCUSSION

Figures 3*A*, at 64°F, and 4*A*, at 86°F, demonstrate that where thick white liquefaction does not occur, the osmotic processes by which water enters the yolk are inhibited, as shown by the fact that the average yolk weight does not increase. Figures 3*B*, 3*C*, 4*B*, and 4*C* show that when these phases of deterioration do take place they proceed simultaneously and to a corresponding degree.

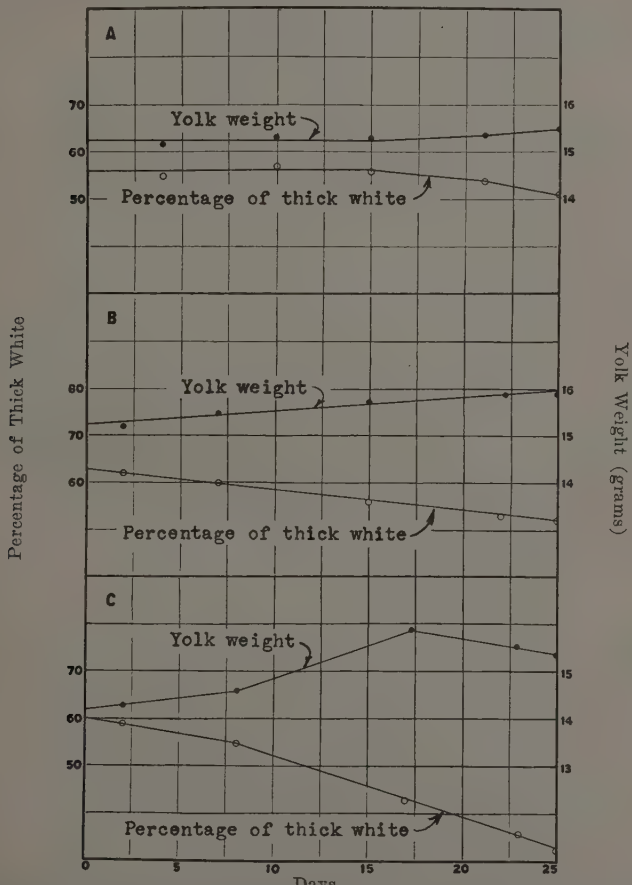

Fig. 3. The changes found in eggs stored at 64° F. Each graph represents data obtained from a series of eggs produced by the same hen. Circles represent percentage of thick white and the filled circles represent yolk weights. Each point shows the average condition of about 5 eggs at the designated time.

The apparent drop in yolk weight in the older eggs as shown in figure 3*C* is probably to be explained by the unusually high shell porosity of the eggs used in obtaining this graph. Under conditions of high porosity the entire egg system, yolk included, may be expected to lose weight after some time in storage.

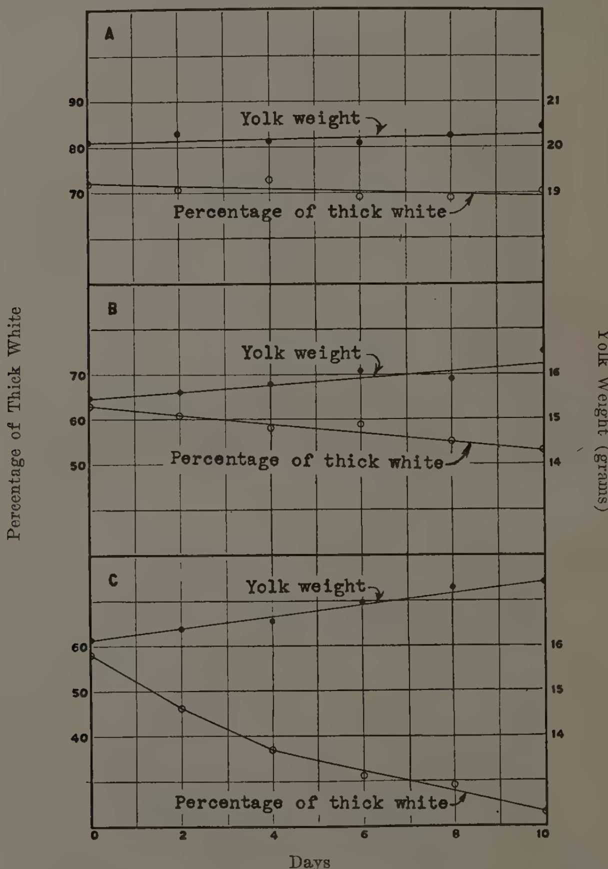

Fig. 4. The changes found in eggs stored at 86° F. As in figure 3, each graph represents the data obtained from a series of eggs produced by the same hen. Circles represent percentage of thick white and the filled circles represent yolk weights. Each point shows the average condition of about 5 eggs at the designated time.

Figures 3*A* and 4*A* are especially interesting in that, although these particular eggs were subjected to the same unfavorable conditions as the others and suffered shrinkage to comparable degrees, they have, nevertheless, demonstrated a high intrinsic keeping power.

The marked differences in the various egg series cannot be explained on the basis of variations in the feeding, housing, etc., of the hens from which the eggs were taken, since these factors were very uniform in these cases. The presented evidence points strongly toward the conclusion that the intrinsic keeping quality of an egg is to be added to the list of characteristics already known to be markedly influenced by the individuality of the hen.

It is apparent from the curves shown that the jelly-like structure of thick white begins to break down as the tendency of water to diffuse into the yolk becomes operative, therefore, *loss of quality in the yolk is accompanied by a corresponding loss in the white.* This is true for every case studied during this work.

The first explanation of these facts which occurs is that the water in thick white, due to the peculiar properties of this jelly-like substance, is held in such a manner that it cannot diffuse into the yolk as long as the thick white is well preserved. This, however, cannot be the true condition since it has been shown (Holst and Almquist, 1931), that the concentration of water in thick white remains exactly equal to that in the associated thin white regardless of losses to the yolk and to the atmosphere. Hence the activity of water in thick white is at all times equal to that of the water in the accompanying thin white, which in turn is nearly equal to that of pure water. The control of the tendencies which may bring about the diffusion of water to the yolk must lie within the yolk itself and may be connected with the increases in alkalinity known to occur in stored eggs.

A logical conclusion concerning the methods discussed is that the two expressions of storage deterioration in eggs, i. e., yolk index and thick white percentage, are correlated, but only as they follow changes which are contemporary. The superiority of the latter measurement lies in the following advantages:

(*a*) Better evidence regarding the initial fresh condition of eggs in respect to an important component, the thick white.
(*b*) Greater simplicity and speed in operation.
(*c*) Less danger of losing the measurements through breakage of the yolk.
(*d*) No necessity of making measurements in a specified time after the egg is opened.
(*e*) Independence of the measurement from shrinkage.

SUMMARY

Shrinkage has little significance as an index to egg quality.

Thick white percentage as an expression of egg quality possesses several points of superiority over the yolk index.

Liquefaction changes in thick white and yolk in stored eggs occur simultaneously or not at all.

The intrinsic keeping quality of an egg is markedly a function of the individuality of the hen.

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VARIABILITY OF SHELL POROSITY IN THE HEN'S EGG[1]

H. J. ALMQUIST[2] AND W. F. HOLST[3]

INTRODUCTION

In connection with the formation of the egg in the domestic hen, Surface (1912) state that the uterus, which is the shell-forming part of the oviduct, possesses at least two kinds of glands, the function of which is to furnish shell-forming material. From one kind calcerous matter is secreted, from the other mucus. The result is a shell which, according to Lillie (1919), consists of three layers, the mammillary layer, the intermediate spongy layer, and the surface cuticle. This heterogeneous envelope is permeable to gases. Lillie explains this characteristic on the basis of a supposed 'network' of pores in the spongy layer, connecting the conical inner ends of the mammillae with pores of the cuticle. This conception of shell porosity no doubt originated with Landois (1865).

The application of the term 'spongy' to the intermediate layer of the egg shell was due to an entirely faulty and misleading experimental procedure. Egg shells were treated with dilute mineral acids. As a matter of course small bubbles of gas, carbon dioxide, appeared scattered all over the exposed shell surface. These bubbles, however, were wrongly interpreted to indicate cavities in the shell and were further assumed to be interconnected by a network of fine channels. Thus, unfortunately, the name 'spongy layer' was introduced into ornithological terminology. Clevisch (1913), in the course of his much more thorough studies of the subject, found the intermediate layer to represent calcium carbonate crystals, densely knitted together by what appeared to be albuminous material. While observing no evidence of a porous network in the intermediate layer he did find

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it to be penetrated by small, definitely tube-like passageways. These passageways or pores were closed at the outer ends by the cuticle which appeared as a nonporous, structureless deposit or seal of a thin and delicate character. It could easily be assumed that a number of outside influences might partly or wholly remove this deposit, thereby exposing the pores.

Investigations by Rizzo (1899) showed that the number of channels in the shells of hen's eggs is very large, varying in the neighborhood of seven thousand per egg. His experimental method was such as to detect all pores, whether originally closed or not. Rizzo used a dye solution, with which he filled the empty egg shell. He then sealed and warmed it. The duration of these experiments, together with the elevated temperature and the pressure developed by expansion of the filling fluid on warming would be expected to cause penetration by the dye at all possible points. Thus the results of Rizzo would represent a uniform upper limit of porosity which might be termed the total or 'potential porosity.' It is apparent from his work, however, that at a somewhat smaller number of points the dye solution used penetrated without assistance to the exterior of the shell, indicating that some of the channels were partially or totally unobstructed at the time of examination. The actual porosity was, therefore, somewhat less than the total or potential porosity found.

On the reasonable supposition that the calcareous portion of the shell is traversed by a large number of these small channels, many of which may be obstructed by organic matter such as the cuticle, it appears that porosity may be a variable, *even in a given individual egg*, depending upon the natural characteristics and treatment of the egg. Thus, if it be recognized that porosity may increase, the limiting value approached may be expressed as the 'potential porosity,' that is, the condition found by Rizzo.

Storage of the egg in air may be expected to lead to drying and shrinking of the external seal, the cuticle, in this way partially opening the already existing and numerous channels. From this physical conception of porosity it will readily be seen that porosity variation of at least three types may result; namely, variation with time, variation with treatment, and variation which may be expected to exist between individual eggs.

In discussing egg-shell porosity, therefore, it is essential to give a definition of the term 'porosity,' although of necessity it will be an arbitrary definition. The term, as used in this publication, is meant to characterize the condition of the egg shell with regard to the num-

ber and distribution of those small channels or pores which, at the time of inspection, offer free passageway to water vapor, air, and carbon dioxide.

The present study, dealing with porosity conditions of hens' eggs investigated under what is believed to be a somewhat original viewpoint, should be of considerable fundamental importance. It is hoped that the information obtained may aid the study of egg quality. This is because porosity—or lack of porosity—must be assumed to be one of the important factors bearing on commercial egg quality and particularly on the preservation of eggs. Of course, other factors, in the egg itself or connected with the condition under which the egg is being stored, must also be assumed to be of significance.

METHODS OF MEASURING SHELL POROSITY

Several methods of measuring egg-shell porosity described in the existing literature were tried out but were later discarded. It is undesirable to apply to the shell any method involving an increase or decrease of pressure, because there is great likelihood of altering the existing porosity by dislodging the pore-filling material. For this reason the method which consists of placing the shell under water in a closed vessel and counting the bubble streams as pressure is reduced is open to objection. It is also unsuitable because of the difficulties in counting the bubble streams and the lack of a permanent record in the shell itself after the test has been made. The use of water or of aqueous solutions is in itself questionable since the effect of water in swelling the mucus in the pores, and later perhaps dissolving it, cannot be determined. Attempts were made to measure the rate of diffusion of gases through the empty shell. The results were inconsistent, largely owing, it was found, to the variation in the degree of dryness of the shell, a variation which can not easily be controlled.

Rizzo's use of a dye solution had great advantages, although his method of application was not satisfactory for the purposes of this work. The method described by Weston and Halnan (1927) of first painting the outside of the shell with a starch solution and later the inside of the shell with a solution of iodine represented an improvement over Rizzo's procedure. The method finally developed and adopted for routine observations in this laboratory, however, consisted of immersing the egg for 2 minutes in a solution of methylene blue in 95 per cent alcohol (3 grams per litre). After immersion the egg is allowed to dry, which requires but a short time. The shell

is then carefully split into halves and the contents are poured out. If the inside of the shell is wiped dry as soon as the egg contents have been removed, a clear and permanent picture of the porosity of the shell remains. An additional immersion of 3 minutes does not bring out more pores, but the spots where penetration has already taken place become enlarged because of diffusion of the dye in the shell membrane.

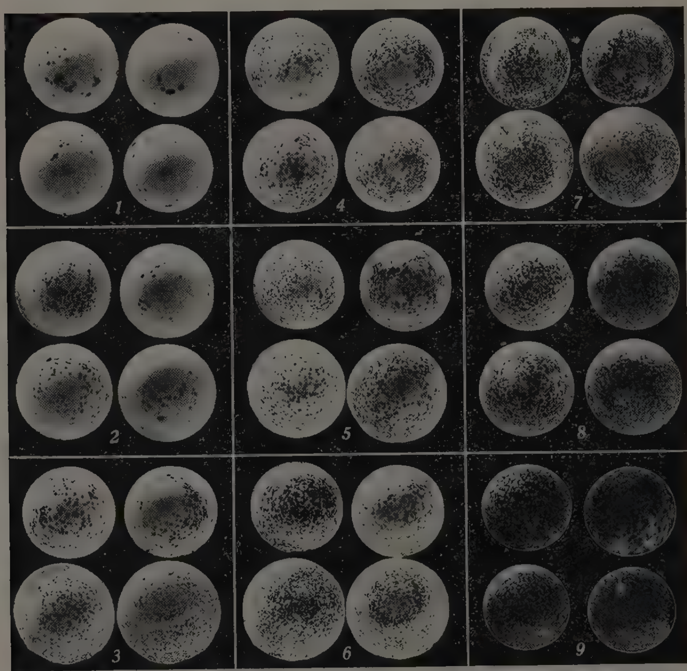

Fig. 1. Shell-porosity standards: the insides of shells adopted as standards of comparison. The numbers 1 to 9 represent increasing shell porosity as shown by the increasing number of small spots on the interior of the shells. Each small spot indicates an open pore. In each porosity class are included a large and a small shell, both halves of each shell being shown. Air-space ends are placed on the left.

In order to classify the shells examined for porosity in this manner a set of standards, covering the range of porosity encountered in this work, was selected and given arbitrary numbers. Later determinations of porosity were compared with these standards and assigned the corresponding numbers. The standards are reproduced in figure 1.

The main advantages of the method are speed, permanence of record, and availability of the egg contents for further inspection. As justification for this method of estimating porosity the following considerations may be advanced:

1. The protein materials which comprise the nonmineral substance of eggs are not soluble in alcohol of this concentration (95 per cent). The mechanism by which the dye penetrates the shell is therefore not one of dissolving the protein-like, pore-filling substance.

2. The alcohol might exert a dehydrating and coagulating action on the cuticle. This would produce an effect similar to ordinary drying and shrinking in reducing the effectiveness of this pore-sealing material. However, it does not seem that this type of action could be effective in the short period required for the test; furthermore, if such action were effective, then, in view of the fact that the potential porosity of all normal egg shells is a fairly uniform and high value, all eggs tested would be expected to show a much greater and more uniform response to the treatment than is actually found to be the case. The variations of porosity and the differences in distribution, as presented later in this article, would be either much less prominent or nonexistent.

3. Observations which have been made by partially submerging emptied half shells in the dye solution have shown that penetration begins at once and that the spots produced merely enlarge during the remainder of the test period.

4. Finally, the relation which the measured porosity has shown to the rate at which eggs lose weight seems to justify confidence in the idea that this method of estimating shell porosity is based upon a fundamental property of the shell, namely, the effectiveness of the shell channels as free pores.

The loss of weight in stored eggs is undoubtedly controlled by the shell porosity. To check the method just described the relation between weight loss and estimated porosity was examined in a number of eggs.

In table 1 are summarized data secured under the direction of the authors.

Eggs were stored 5 to 6 days at 86° F and at constant humidity. Loss of weight was determined by accurate weighings and expressed as percentage of fresh weight lost per egg per day. The porosity numbers were assigned as described previously in this article. The results of the two determinations were collected for some time in an independent manner, then brought together, calculated to a common basis, and compared.

TABLE 1
THE RELATION OF SHELL-POROSITY NUMBER TO THE MEASURED LOSS OF WEIGHT IN HEN'S EGGS

	Porosity numbers*								
	1	2	3	4	5	6	7	8	9
Total number of eggs of each porosity rating	1	3	16	20	22	18	16	15	11
Average per cent of weight lost per egg per day	0 212	0.442	0 502	0.532	0 573	0 603	0.691	0.917	1.047

* See figure 1 for shell-porosity standards.

The table clearly illustrates a parallel trend in assigned porosity numbers and measured loss of weight. If the loss of weight is plotted against porosity number (fig. 2), it will be seen that a practically linear relation exists over the range 2 to 7. The loss of weight increases sharply with the porosity numbers 7, 8, and 9, indicating that these notations represent greater increments in porosity than do the preceding ones. Perhaps this range should be subdivided into a somewhat greater number of comparative standards to achieve greater consistency with the lower porosity numbers.

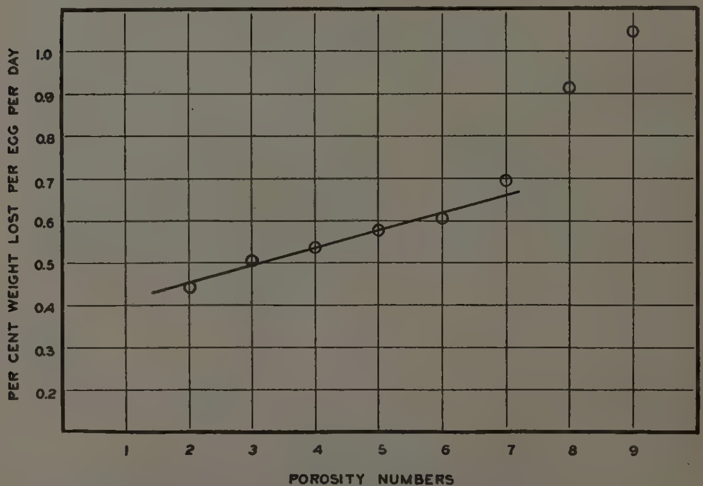

Fig. 2. The agreement between the assigned shell porosity numbers and the measured rate of losing weight in 122 hens' eggs at 86° F.

It cannot be claimed for this method of evaluating porosity that an absolute measure is achieved. Although tests may be conducted in a uniform manner the final ratings depend upon personal judgment. Human errors may be reduced by working with larger numbers of eggs and in a random manner so that preconceived ideas may not prevail in classifying a particular egg or the egg from a particular hen. As far as possible this was done. It is a matter of practical impossibility to make an actual count of pores in a large number of egg shells. The method of classification just described sacrifices accuracy for speed in the hope that, on the average and with large numbers of eggs, results may still be significant.

The procedure used gives an approximate quantitative measure of variability in shell porosity. It has also shown certain changes in shell porosity with time and temperature not previously reported.

RESULTS

Eggs from a group of more than 50 hens were examined. Included in this group were eggs showing wide differences with respect to shell characteristics, such as thickness and smoothness. In all more than 500 shells were examined for porosity. At the same time data were taken regarding shrinkage and keeping qualities. The latter work is still in progress.

Fresh Eggs.—The examination of fresh eggs demonstrated a striking variability in porosity in eggs from different birds. Eggs from the same bird were usually found to be fairly uniform in this respect.

Statements in the literature create the impression that shell porosity is greater or that pores are larger at the air space (Rizzo, 1899; Dunn, 1923; and Swenson and Mottern, 1930), but observations made in this laboratory on eggs one day or less in age indicated that this condition is far from being general. There is no apparent fundamental reason for the existence of greater porosity at air spaces in fresh eggs, but this may be expected in older eggs, for, at the air space, the shell is not in contact with watery material but is bounded on both sides by gases. This probably leads to a faster drying of the shell and of the pore-filling material and a corresponding faster opening up of the pores in this part of the egg.

Figure 3, *A* and *B*, represents shells in which very little porosity was found at the air space. The position of the air space is indicated by the circle. Both halves of the shell are shown, the air space ends being placed on the left in these and in all other cases.

Figure 3*C* illustrates some of the few cases in which porosity was found to be distinctly greater at the air-space end. It will be noted that the great degree of porosity is not necessarily confined to the shell portion forming the air space.

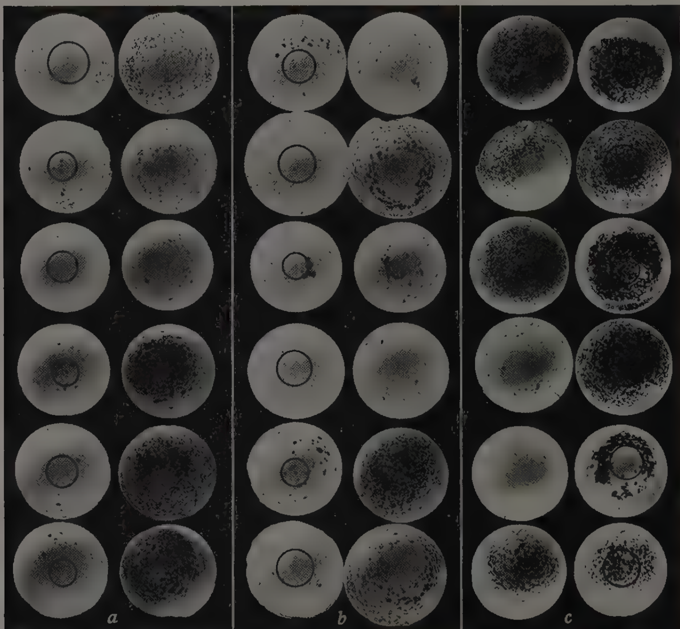

Fig. 3. Abnormal distributions of porosity in shells of fresh eggs. Both halves of each shell are shown. The air spaces occupied the regions indicated by the circles.

The standards (fig. 1) illustrate the type of porosity most commonly found in fresh shells. About 80 per cent of the shells examined showed a uniformly distributed porosity of this nature. The variability of this porosity in fresh eggs is indicated by the standards. All degrees of porosity represented by these figures were found in fresh shells, the condition most frequently met, however, being represented by porosity numbers 4 and 5.

Stored Eggs.—In order to note possible changes of shell porosity during storage, eggs were stored at different temperatures—at room temperature (about 68° F), at 86° F, and at 102° F. At the last two

temperatures the humidity was maintained at about 75 per cent. Examination of the egg shells after storage revealed certain significant facts.

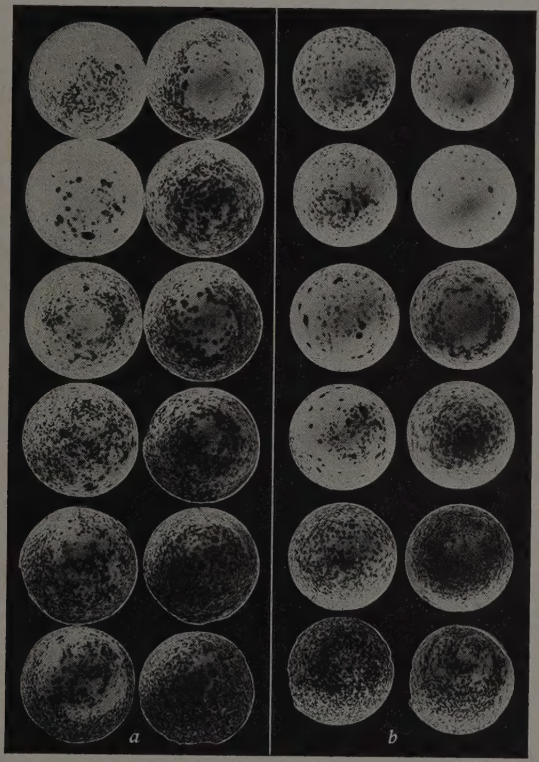

Fig. 4. Increases in porosity found at room conditions over a twenty-five day period. Egg age increases in five-day increments from top to bottom of figure. Air-space halves are placed on the left. All shells in *a* are from one hen, all shells in *b* from another.

While heretofore porosity has been considered a rather fixed characteristic of the shell, it was apparent that porosity is not necessarily constant, that it may increase with the age of the egg, and more rapidly with higher storage temperature. A few exceptions to these findings resulted when eggs from the same hen started at a rather high initial prorosity and maintained this at about the same level over a period of 25 days, when stored at room conditions.

The increases in porosity as observed may partly explain the abnormally poor keeping quality of eggs which have been removed from storage. In particular eggs stored under conditions of low humidity would probably show an increase in porosity which would greatly favor their deterioration upon removal from storage.

In figure 4 are shown two series of shells, each series from an individual bird, which illustrate porosity increases encountered in eggs stored at room conditions over a period of 25 days. The shells are 5 days apart in storage age.

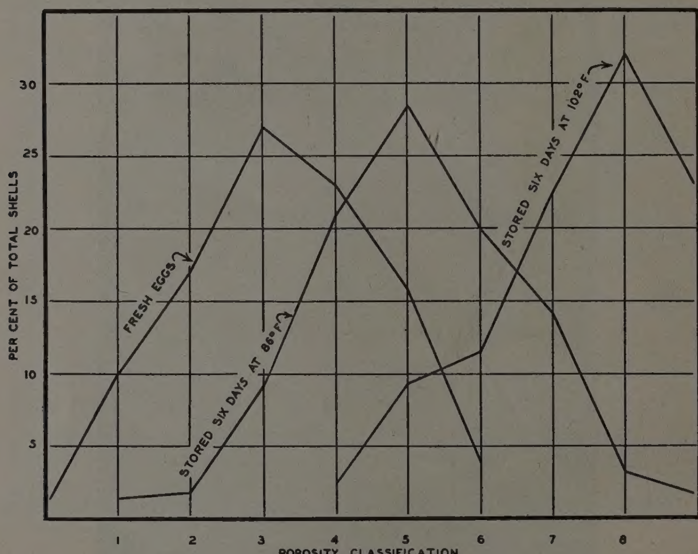

Fig. 5. Distribution of porosity in fresh eggs and eggs stored for six days at 86° F and at 102° F.

It is possible that the apparent increases in shell porosity with age may be due to differences in initial porosity. The changes noted, however, were found to be general, and for the most part the porosity in the older shells is far greater than the average initial porosity of eggs from the same hen. A more uniform distribution of the pores in the shell is invariably associated with an increase in degree of porosity.

In order to express the effects of storage on porosity at the various temperatures quantitatively, the results of an investigation have been shown graphically in figure 5. In this figure, one curve represents the

distribution of porosity in 72 fresh shells, one day or less in age, which came from a group of 12 hens used in this work. Six eggs were used from each bird. A second curve shows the distribution of porosity found in an equal total number of shells and with the same individual number from the same birds, after the eggs had been stored for 6 days at 86° F. The third curve shows results from inspection of random eggs, largely from the same hens, after 6 or 7 days at 102° F. The first and second curves are entirely comparable. The shift of the most probable porosity toward a higher value after 6 days' storage is significant of a tendency toward an increase in porosity. It is also noteworthy that the porosity of eggs at incubation temperature (102° F) tends to reach a still higher value in a similar period of time.

SUMMARY

A new method for the study of egg-shell porosity has been suggested.

The shell porosity in fresh eggs, i. e., the initial porosity, with but few exceptions, has been found to be low.

Egg shells are subject to changes in porosity when the eggs are stored. Shell porosity may increase with duration of storage, more rapidly at higher temperatures, and approach a maximum which is nearly uniform for all eggs with regard to degree and distribution.

Egg-shell porosity appears to be nearly uniform for the eggs of a particular hen, but shows differences for different individuals.

Porosity in fresh egg shells is rather uniformly distributed. It is not generally greater in the air-space region of the egg.

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